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SATELLITE AND ROCKET OBSERVATIONS OF EQUATORIAL SPREAD-F IRREGU--ETC(U)
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*Sachs/Freeman Associates, Inc., Bowie, MD 20715
On leave from Punjabi University, Patiala, Indiana
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Recent rocket and satellite measurements of equatorial F-region irregularities have been able to resolve wavelengths comparable to the meter-size sensitivities of the Jicamarca and Altair radar backscatter techniques. In a July 1979 rocket campaign at the Kwajalein Atoll, vertical profile measurements by "in-situ" plasma probes showed the F-region marked by a number of large scale plasma depletions, each having its own distribution of smaller scale irregularities and a trend toward a co-location of the more intense irregularities with positive gradients of larger scale features. Similar measurements on the S3-4 Ionospheric Irregularities Satellite have shown large scale depletions (1-3 orders of magnitude) with east-west asymmetries that point toward the western wall as

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20. Abstract (Continued)

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the ~~sight~~ for the more intense plasma density fluctuations. The combined rocket and satellite measurements provide a two-dimensional model of macroscopic F-region depletions with small structures tending to develop more readily on the top and western boundaries. The model and associated power spectral analyses is in concert with a developing catalog of radar observations and the predictions of numerical simulations which employ the Rayleigh-Taylor instability as the primary mechanism for the generation of intermediate wavelength irregularities.

CONTENTS

SATELLITE AND ROCKET OBSERVATIONS OF EQUATORIAL SPREAD-F IRREGULARITIES: A TWO-DIMENSIONAL MODEL

I. INTRODUCTION

Recently, there have been considerable advances in the understanding of equatorial spread-F as a result of improved ground based radar observations and coordinated "in situ" measurements. The long standing Jicamarca radar results (e.g., Woodman and LaHoz (1976) and associated references) have been studied in greater detail by the expanded capabilities of the Altair radar facility in the Kwajalein Atoll (Tsunoda and Towle, 1980). These more recent results have investigated plume development in an east-west cross-section and provided some tentative identification of plume elements with local F-region plasma depletions (Tsunoda, 1980a,b).

Early efforts to examine the exact relationship between radar plumes and ionospheric depletions by performing simultaneous "in situ" and ground-based radar observations (Kelley et al., 1976; Morse et al., 1977) were limited to conditions of bottomside spread-F and required extrapolations in space and time to establish correlations. These frustrations, as well as two unsuccessful attempts at Kwajalein in 1977 and 1978, were finally relieved by the successful DNA/PLUMEX campaign in 1979 (Szuszczewicz et al., 1980a) which definitively established the co-location of intense radar returns with the upper region of a topside F-layer depletion. The PLUMEX results also provided the first vertical profile of large-scale plasma depletions with superimposed distributions of smaller scale irregularities.

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In an attempt to establish a 2-dimensional "in situ" profile that complements the developing catalog of Altair observations, we present in this paper a composite of rocket and satellite observations, from the PLUMEX campaign on the one hand and the S3-4 satellite on the other. These results are summarized in subsequent sections and synthesized in a way that suggests a two-dimensional model of macroscopic F-region depletions with smaller scale structures tending to develop more readily on the top and western boundaries.

II. ROCKET-BORNE MEASUREMENTS

The coordinated measurements of equatorial spread-F conducted during July 1979 at the Kwajalein Atoll involved the launch of two instrumented rocket payloads designed to probe the detailed "in situ" structure of the turbulent ionospheric plasma. The first launch operation (PLUMEX I; 17 July 1979; 0031:30.25 LT) was conducted during the late phase in the development and decay of spread-F. The associated results and discussions of ground-based and rocket-borne diagnostics have been presented by Szuszczewicz et al. (1980a,b).

For purposes of comparison with subsequent presentations of S3-4 satellite data we show here in Figure 1 the upleg measurements of relative density as presented by correlated ion- (I_B^i) and electron-saturation $I_e^i(V^+)$ currents collected by a pair of on-board pulsed-plasma-probes (Holmes and Szuszczewicz, 1975; Szuszczewicz and Holmes, 1980) in the PLUMEX I operation. The ordinate has a linear scale for time-after-launch with altitude superimposed at 50 second increments. (Because ion and electron

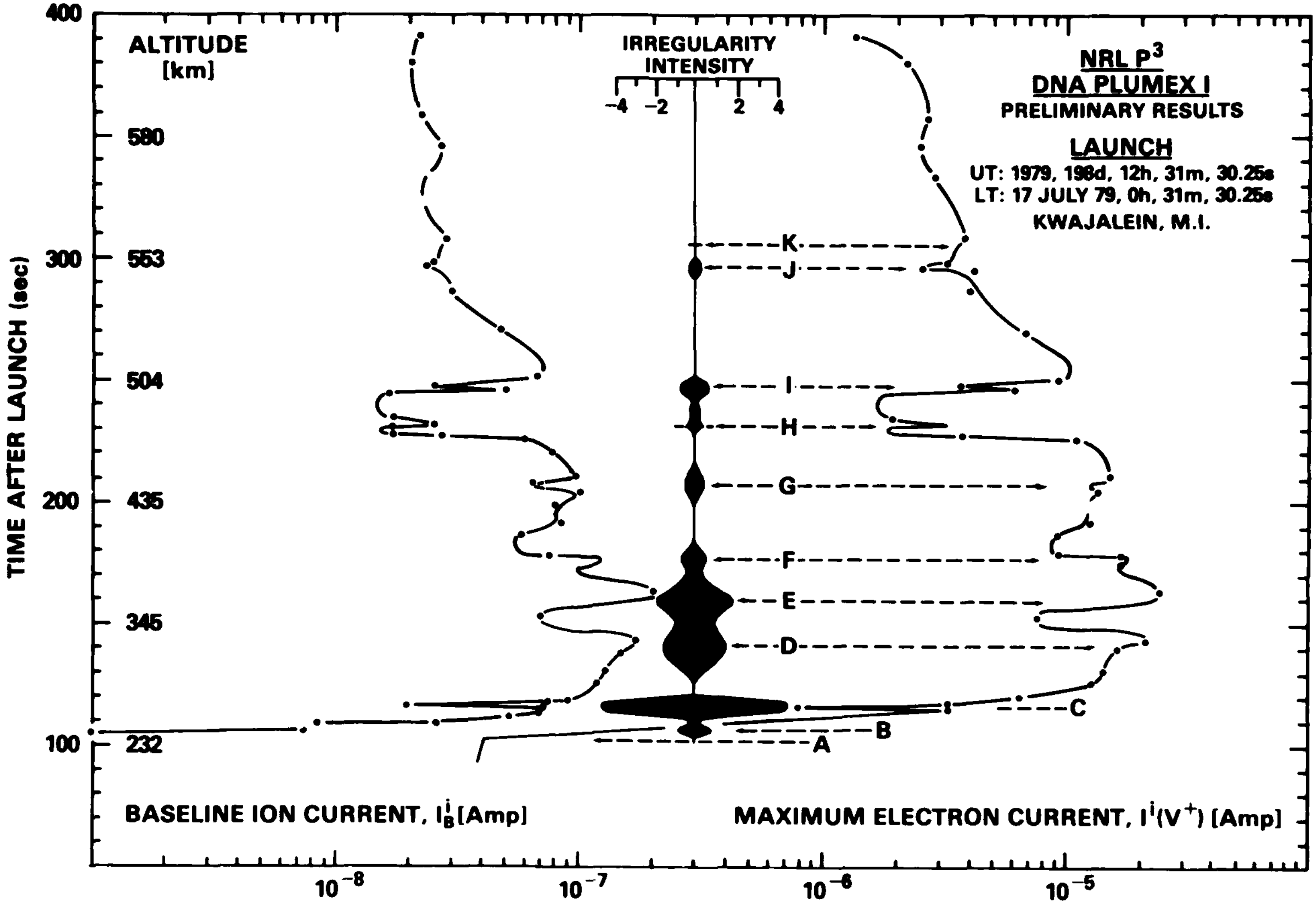

Fig. 1 — Relative electron density profile of macroscale features as measured simultaneously by ion and electron saturation probe currents collected on the upleg trajectory of PLUMEX I. The "irregularity intensity" provides an approximate measure of smaller scale structure with a + 4 intensity approximately equal to ± 80% fluctuations about a linear detrend. (From Szuszewicz et al. 1980.)

saturation currents have significantly different sensitivities to velocity, sheath and magnetic field effects, variations in I_B^i and $I_e^i(V^+)$ not mutually corroborated were attributed to the various aspect sensitivities and excluded from Figure 1. This approach facilitated analysis, reduced computer time, and established credibility in the interpretation of the curves as relative electron density profiles.)

The results in Figure 1 show that a number of major depletions ($\Delta N_e/N_e^o \lesssim 0.9$) were distributed throughout the F-region. Each of the large scale depletions (identified alphabetically) has its own distribution of irregularities, illustrated in Figure 2 by the expanded view of regions C, D, H and I. It is clear that "C" is not a single narrow biteout but a collection of rather large irregular structures extending over a total altitude domain of about 12 km. (Vehicle velocity in region C was 2.4 km/sec.) To develop a quantitative view of irregularity fluctuations observed in the F-region, contiguous linear detrends over 4-second intervals were executed throughout the entire upleg trajectory. The variations about those linear detrends were then plotted in Figure 1 as "Irregularity Intensity", with a maximum relative scale of $\pm$ 4. A fluctuation as great as $\pm$ 4 approximately represents a $\pm$ 80% fluctuation about the linear detrend. (Correlation of these results with macroscale gradients and Altair backscatter contours are discussed by Szuszczewicz et al., 1980a). The results show that the most intense irregularities occurred on the bottomside gradient (region C) with corresponding

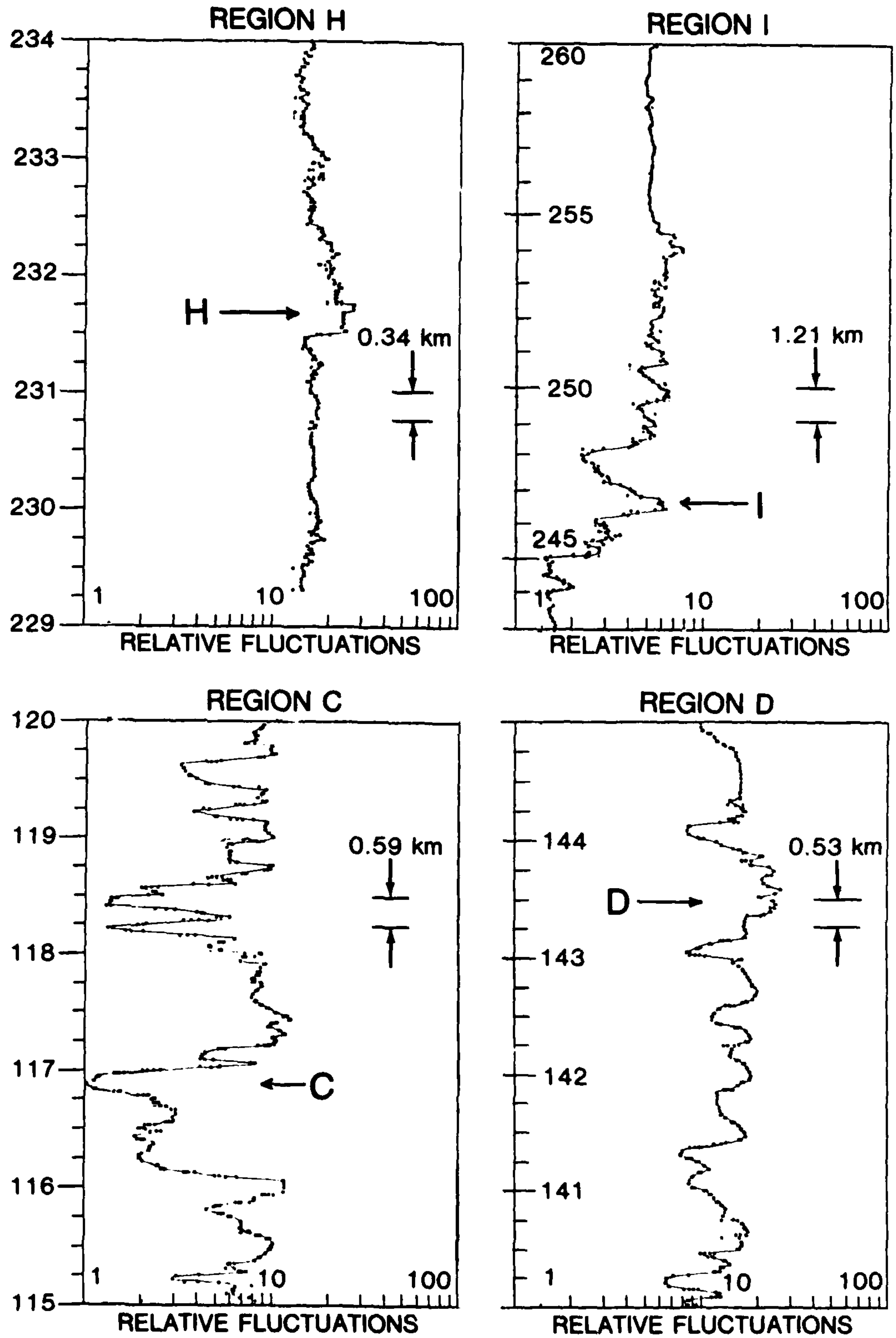

Fig. 2 — Expanded views of density fluctuations observed in regions C, D, H and I of Figure 1.

measurements at all other altitudes at a much lower level. We note that the fluctuations in the largest depletion (region H-I) are smaller than those at "C". Furthermore, the fluctuations at C, D, E and I are more intense than at adjacent locations; and C, D, E and I are co-located with positive density gradients of large scale features.

III. S3-4 SATELLITE RESULTS

While rocket-borne instrumentation can provide vertical profiles of irregularities, a circular or near-circular orbiting satellite with high resolution instrumentation is required to assemble irregularity intensities and power law behavior in the horizontal plane. The S3-4 satellite carries just such an experiment.

The S3-4 ionospheric irregularities experiment employs a pair of pulsed-plasma-probes (Holmes and Szuszczewicz, 1975; Szuszczewicz and Holmes, 1980) on a polar (96.4° inclination), sun-synchronous (2230 hr LT, equatorial crossing), F-region orbiting satellite. The experiment provides direct measurements of the ionospheric state (N_e, T_e), its condition of irregularity (δN_e), and associated electron density fluctuation power spectra ($P(k)$) with 5-20 meter resolution.

Figure 3 presents a sample of relative electron density data collected during a nighttime equatorial crossing with the satellite orbiting at an altitude of 240 km with a velocity of 7.53 km/sec. The velocity component perpendicular to the geomagnetic field is 2.0 km/sec. 50 seconds of data are displayed covering a total horizontal extent equal to 366 km, moving from east-to-west with increasing time.

The data reveal four large scale depletions ranging up to 98 km wide and a factor of 300 in depth, with smaller scale structure visible down to a fraction of a kilometer. The upper portion of Figure 3 presents "irregularity intensity" as measured by relative fluctuations about continuous 0.27 second (2.1 km) linear detrends.

Further discussion is facilitated by identifying certain features in Figure 3. First, there are clearly defined regions of undisturbed background ionosphere, marked alphabetically A through D; the smoothness of the relative density and the corresponding 0% fluctuations attest to their undisturbed nature. The eastern boundary is defined as the region of density gradient moving westward from an undisturbed domain to the least lower bound of relative plasma density in the depletion. Everything to the west of that minimum is defined as the western boundary. Admittedly these definitions leave no room for a region that might be called the "depletion center", but depletions 3 and 4 suggest that there is no easily defined "depletion center". This is also borne out by other sets of P^3 data.

Focussing on depletions 3 and 4, we see that the irregularity intensities are 2 to 3 times larger on the western boundary than on its eastern counterpart. This same relationship is true in depletions 1 and 2, but only after a qualification that suggests that 1 and 2 are halves of a larger depletion bounded by A and B. This is supported in part by the non-existence of a quiescient ionosphere between the two. When

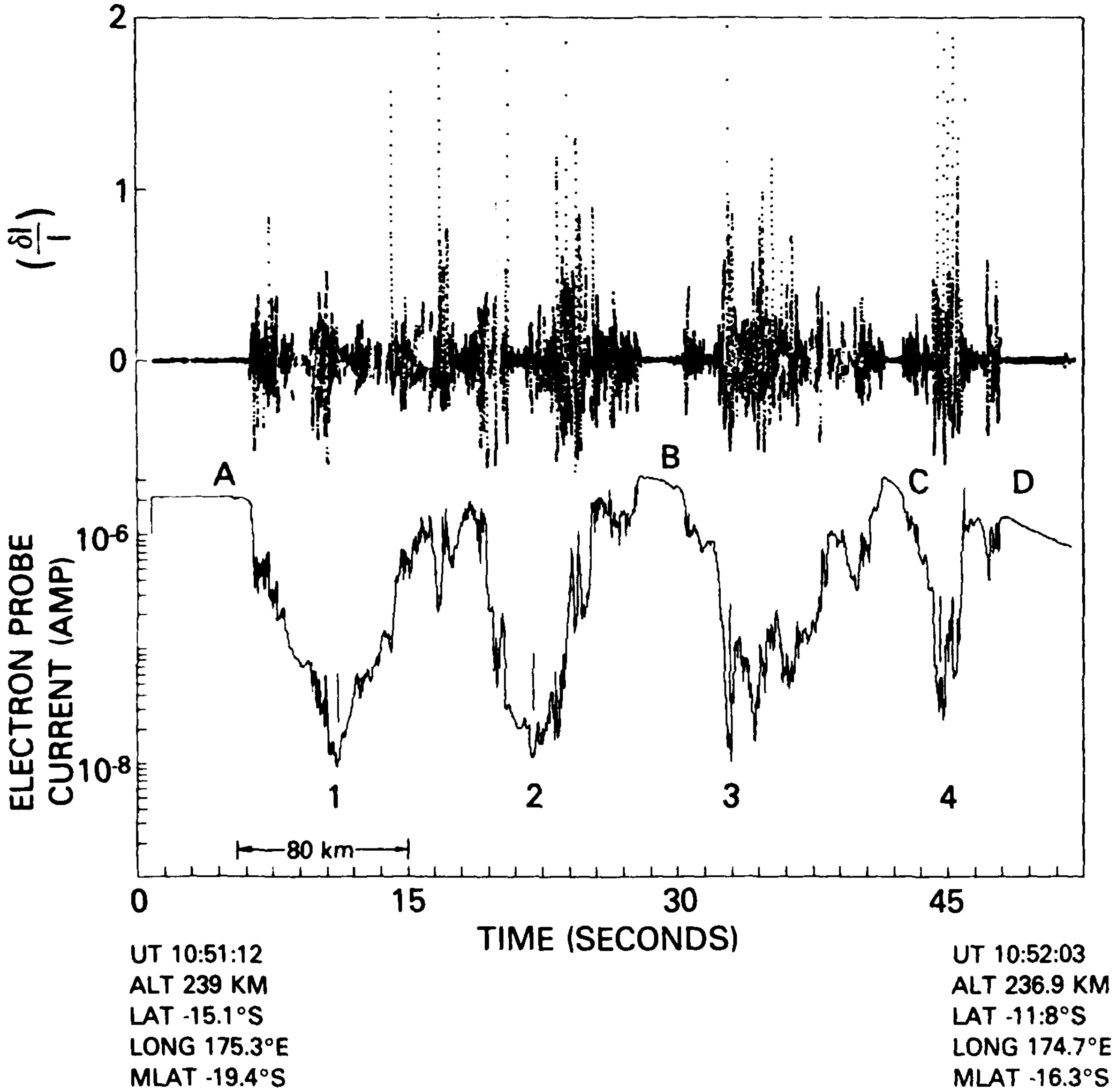

Fig. 3 — The electron density variations as measured by the electron probe aboard S3-4 on rev. #2123. On the top is the irregularity intensity ($\delta I/I$) determined over contiguous 2.1 km intervals throughout the depletions.

viewed from this perspective the western boundary is approximately twice as intense in irregularity intensity as the eastern boundary.

Signatures in irregularity strengths and relationships to plasma instability mechanisms can be further explored through power spectral density analyses. We present in Figure 4 just such results for each of the boundaries in Figure 3 (1E and 1W refer respectively to the eastern and western boundary of depletion number 1). Power spectral analyses are presented across the boundaries of each of the four depletions with spectral indices (η, in a spectral fit to $P = P_o f^{-n}$) ranging from 1.9 to 2.3. (These indices are in agreement with the work of Keskinen et al. (1980) where numerical simulations predict n = 2.0 to 2.5 for horizontal irregularity structures perpendicular to $\bar{B}$. This result runs parallel to an earlier comparison (Szuszczewicz and Holmes, 1980; Keskinen et al. 1980b) which showed that the power spectral index across region C in PLUMEX I also agreed with the predictions of Keskinen et al (1980a) in the vertical plane.) More important to the discussion of east-west asymmetries is the ratio of the spectral strengths (P_o) across the two boundaries. By defining P_1 as P_o(West)/P_o(East), we find the ratio P_1 to extend from 1.4 to 11.3, i.e., the irregularity spectral strength on the western wall is 1.4 to 11.3 times more intense than on the eastern counterpart.

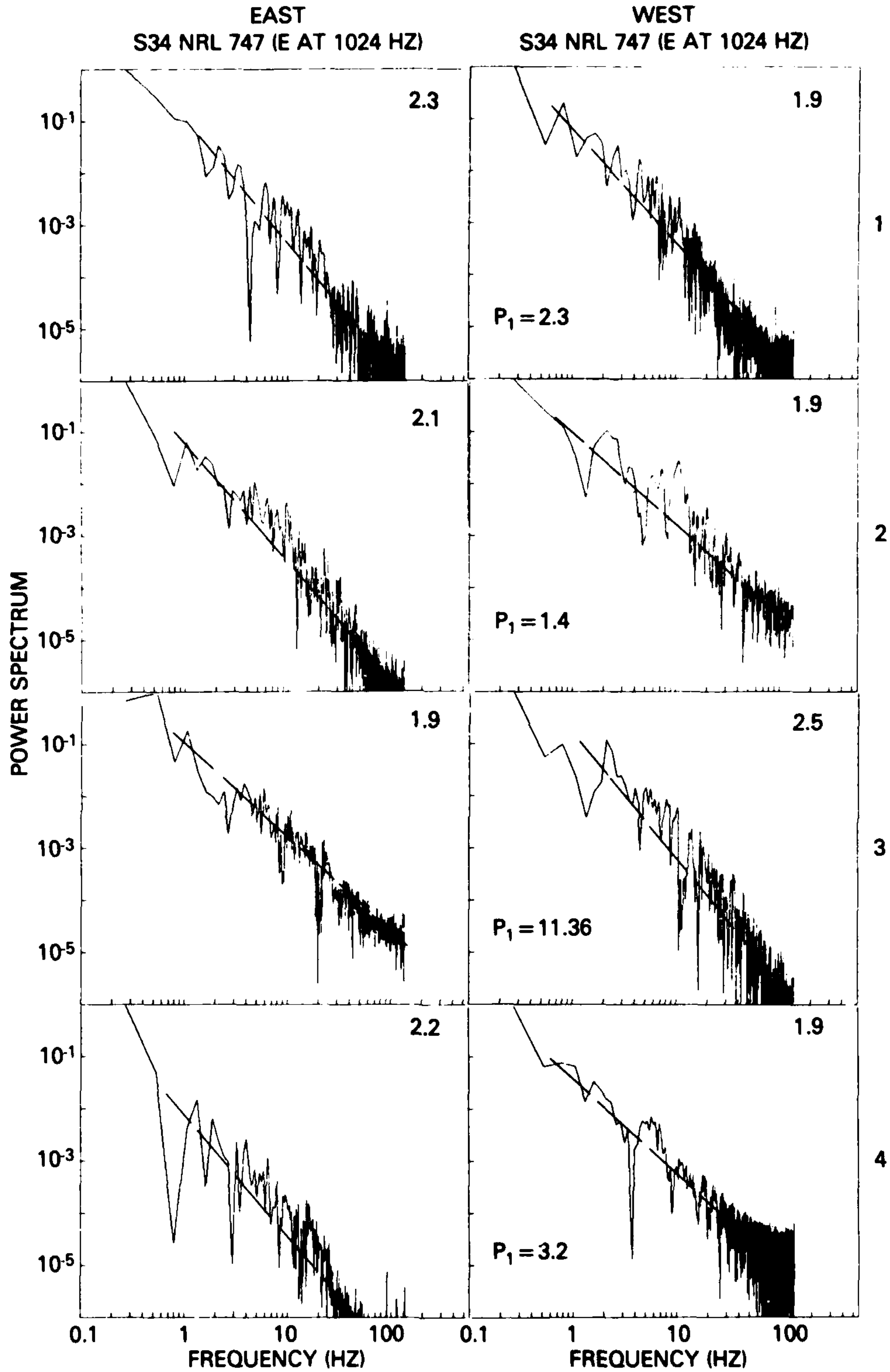

Fig. 4 — Power spectral analyses across the boundaries of the four depletions (1 thru 4) in Figure 3. The number in the upper portion of each panel is the spectral index n, in a $P=P_o f^{-n}$ fit to the data. The value P_1 shown in each right hand panel corresponds to the ratio of spectral strengths $P_1 \equiv P_o$ (western boundary) $\div$ P_o (eastern boundary).

These results are in concert with the radar observations of Tsunoda (1979) which show that the bottomside backscatter strength is often asymmetric in the east-west plane, with the western side of the plumes being the more intense. The combined observations support a model of E-W asymmetry which allows for a neutral-wind-driven instability-growth-rate enhancement on the western side of a rising bottomside F-region depletion (Tsunoda, 1979).

IV. CONCLUSIONS

The combination of recent rocket and satellite data allows for the development of a two-dimensional empirical model of equatorial depletions and associated irregularities. Elements in the data have led to the following conclusions:

1) Equatorial depletions are macrostructures within which much smaller scale irregularities are imbedded;

2) These smaller scale irregularities (in the vertical plane) tend to derive their energies from positive density gradients on the topside of local depletions;

3) Vertical and horizontal power spectral analyses display indices from 1.8 to 2.5, a result which is consistent with Rayleigh-Taylor instability generation of intermediate wavelength irregularities during the occurrence of equatorial spread-F (Keskinen et al. 1980a);

4) When viewed horizontally, bottomside depletions have and east-west asymmetry with the more intense fluctuations and spectral strengths being observed on the western boundary.

This result is consistent with the radar measurements of Tsunoda (1979) and scintillation observations of Livingston et al. (1980);

5) The combination of all results leads to a two-dimensional model of macroscopic F-region depletions with smaller scale structures developing on the top and western boundaries. This model and associated spectral indices fully supports the computational work of Keskinen et al. (1980a).

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